MINE ROCK CHARACTERIZATION AND IDENTIFICATION OF "NEUTRAL" ROCK AT THE ZORTMAN AND LANDUSKY MINES, LITTLE ROCKY MOUNTAINS, PHILLIPS COUNTY, NORTH-CENTRAL MONTANA[1]

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ABSTRACT

In-pit identification of neutral waste rock at the Zortman and Landusky minesites in Montana, by visual and chemical analyses, will assist in proper segregation and placement of rock so that soil and water resources can be protected. The use of too few or very general segregation criteria to identify neutral waste can result in ineffective waste rock segregation. Conversely, the use of overly restrictive criteria can result in the unnecessary loss of valuable reclamation material that would otherwise have to be mined elsewhere and hauled to the site. Recognition of nonreactive materials can be accomplished on a site specific basis with the use of visual observation and simple chemical analyses. The choice of chemical parameters used to analyze rock samples is constrained by the length of time needed to conduct the test. These analyses must require no more than 24 hours to complete so mining can proceed without delay. Limits set for the chosen parameters must be reasonable and defensible.

To achieve these objectives over one thousand samples were collected at the Zortman and Landusky minesites and classified by rock type, total sulfur content, net neutralizing potential (NNP), and paste pH. In addition, over 22 humidity cell kinetic tests were conducted to help corroborate static results for waste rock. Another 8 humidity cells were configured in series to test waste rock blending and waste rock/limestone capping alternatives as mitigation for acid rock drainage. Leachates were analyzed for pH, conductivity, alkalinity, acidity, sulfate, Al, Cd, Cu, Fe, Mn, Zn, Mg, and Cr in some cases.

Petrographic analysis, as well as total sulfur content, paste pH, and static and kinetic test results identified three geochemically different waste rock groups: 1) Archean amphibolite gneiss and Paleozoic carbonates and shales, 2) Tertiary syenite porphyry, and 3) other less abundant Tertiary igneous and Archean metamorphic rocks.

In-pit identification of neutral waste rock is now accomplished by simply knowing the rock type, total sulfur content, paste pH, and the NNP. Neutral waste is identified as Archean amphibolite gneiss and Paleozoic shale or carbonate with total sulfur content $\leq$ 0.80% and paste pH $\geq$ 6.0; and Tertiary syenite porphyry with total sulfur concentration $\leq$ 0.20%, NNP $\geq$ 0 tons $CaCO_3$ equivalent per thousand tons waste rock (t/Kt), and a paste pH $\geq$ 6.5. The unaltered carbonate rock units are suitable for any purpose and do not have to meet the total sulfur criteria due to possible interferences from gypsum. All other lithologies were excluded as neutral waste due to insufficient sampling, mineralogical variability, unfavorable kinetic results, and/or the low abundance of these rock types.

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[1] Paper to be posted at http://www.info-mine.com/technomine/enviromine/case_hist/ch2.html

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INTRODUCTION

Acid rock drainage is evident downgradient from facilities at both the Landusky and Zortman minesites. Zortman Mining Inc (ZMI), the operator, has proposed to extend mining at both minesites. At Zortman 80 million tons of ore and 60 million tons of waste is proposed to be mined and placed in new facilities. For Landusky 7.6 million tons of ore and 7 million tons of waste rock would report to existing facilities. Rock types/percentages proposed for mining are shown in Tables 1 and 2. These proposed actions would require the construction of rock drains, the use of waste as fill, and an increase in the area to be reclaimed upon closure (ZMI, 1992). Key among the reclamation objectives are the installation of dry water balance covers to limit the flux of water through the facilities and to limit soil acidification. Neutral waste would be needed as reclamation covers and, where applicable, as material for construction and fill. Reactive waste would need to be isolated from air and water. As a result of proposed mining extensions and remediation activities at the Zortman and Landusky mine sites, the operator has proposed one segregation criterion. Any waste rock with less than 0.20% total sulfur would be considered suitable as reclamation material.

In a previous environmental analysis (EA) conducted for the Landusky minesite remediation (USDI and DSL, 1993), the agencies determined that the use of this single criterion was not sufficient to segregate reactive material, especially when considering certain igneous rock types. The Record of Decision adopted the use of stringent criteria for defining neutral waste. Based on the limited kinetic data available at the time, the following very conservative criteria were imposed: 1) acid neutralizing potential greater than three times the acid generating potential (NP > 3 AP) and 2) net neutralizing potential greater than +20 (Saskatchewan Environment, 1992). These criteria were adopted and are currently in use at the Landusky minesite.

Problem Statement

With subsequent compilation and interpretation of the entire geologic and geochemical data set, including more extensive kinetic testing and SEM/EDX analyses, it was determined that neither the proponent's nor the agencies' previous limits for criteria were entirely appropriate. It appears that ZMI's definition of neutral waste was very general and the agencies' previous definition of neutral waste was overly stringent. *The use of the proponents criterion would probably allow some reactive waste to be placed improperly. The use of the agencies' limits would unnecessarily restrict the amount of suitable material available for reclamation purposes.* It is important to note that the rock type was not included as a criterion for either the original proposal or the agencies' alternative in the Landusky EA. This study added rock type and paste pH to the previous criteria and established more reasonable, appropriate limits for all criteria. Rock type, the most important criterion, was used to provide an effective approach to identify neutral and reactive rock so that suitable material would be available to remediate the environment and to prevent improper placement of reactive waste rock.

ROCK TYPES

The Zortman and Landusky gold telluride ore deposits occur in Tertiary syenite porphyry stocks which intrude Paleozoic sedimentary and Precambrian metamorphic units in the Little Rocky Mountains of north-central Montana (Figure 1a). The dominant rock type for ore and waste at both minesites is Tertiary syenite porphyry. Precambrian amphibolite gneiss at the Zortman minesite and Paleozoic sedimentary units at Landusky comprise the next two most abundant rock types to be encountered during mining.

Giles (1983) describes the regional geology. Geology and geochemistry of the Little Rocky Mountains are presented by Russell (1991) and White (1989). Other sources of information include Bailey's thesis (1974) and Brockunier's doctoral dissertation (1936). Richardson (1973) describes the local geology and paragenesis in his thesis. Using SEM/EDX analysis of core and heavy concentrates, Honea (1992) has conducted an extensive study of ore mineralogy and pyrite crystal form and trace impurities.

Table 1. Zortman Mine Rock Types Proposed for Mining

Relative Age and Rock Type	Percent of Rock to be Mined	Percent Ore	Percent Waste
Tertiary Syenite Porphyry	65%	36%	29%
Precambrian Amphibolites	13%	6%	7%
Precambrian Felsic Gneiss	8%	6%	2%
Tertiary Monzonite	6%	4%	2%
Quartzite, Breccia, & Paleozoic Sedimentary Units	8%	5%	3%
Total	100%	57%	43%

Table 2. Landusky Mine Rock Types Proposed for Mining

Relative Age and Rock Type	Percent of Rock to be Mined	Percent Ore	Percent Waste
Tertiary Porphyry and Breccia	81%	41%	40%
Paleozoic Sedimentary Units	16%	9%	7%
Archean Metamorphic	3%	2%	1%
Total	100%	52%	48%

GEOCHEMICAL TESTING METHODS

Although the study focused on identifying neutral waste rock at the Zortman mine, the identification of layering alternatives or blending amendments which could be used to mitigate acid production in reactive waste rock was studied as well. Petrographic classification as well as paste pH and static tests were conducted with samples from both minesites collected during 1992 and 1993 developmental drilling. The number of samples per lithology was roughly proportional to the amount of rock expected to be mined. For brevity, only results for Zortman waste rock are provided in Table 3. Humidity cell testing was performed using samples collected for the two dominant rock types, syenite porphyry and amphibolite gneiss, as well as other less dominant lithologies. Interpretations of kinetic data were extrapolated to the Landusky deposit due to marked similarities with respect to geologic setting, mineralogy, and ore deposit type. Conclusions are based on empirical estimations and qualitative assessment using best professional judgement.

Over a thousand paste pH analyses were conducted for waste rock to evaluate the existing pH of the rock material at both minesites. This parameter was measured and recorded quickly using accepted standard procedures. It was recognized early in the sampling event that this parameter would provide useful information as to the extent of acidification/oxidation of a certain sample independent of the total sulfur content. A low paste pH might be indicative of sulfides that have reacted to produce acid or oxidation products. A high paste pH could be indicative of a high concentration of alkaline minerals in the sample or might be generated in alkaline rock with sulfide that has not yet reacted.

Static testing using acid-base accounting was performed on approximately 1284 Zortman/Landusky waste rock samples. The acid generating potential (AP) was measured quickly by total sulfur determination using a Leco

SC-32 analyzer. The neutralizing potential (NP) was estimated using an experimental protocol which estimates carbonate by measuring carbon dioxide production when an aliquot of sample is exposed to dilute cold acid (Miller, 1995).

Geochemical kinetic tests involved accelerated weathering of samples under laboratory controlled conditions by leaching moist, hot air through the material in a humidity cell and analyzing the leachate. Unlike static testing, this type of test attempts to assesses acid generation as a function of time. Testing was conducted in two phases: 11 cells were leached for 20 weeks and later 13 more cells were leached for 45+ weeks. Eight of the 20-week cells were configured in series to evaluate the effects of layering reclamation covers and underdrain material. Only one cell was conducted to evaluate waste rock blending. This cell was 60% amphibolite, 30% syenite and 10% quartz monzonite.

RESULTS, INTERPRETATION, AND CONCLUSIONS

Results from petrographic identification, paste pH, and static and kinetic testing were used to evaluate the adequacy of ZMI's proposed reclamation plans and definition of neutral waste. Various methods, criteria, and limits were tested for their usefulness in identifying neutral rock by correlating static results with kinetic results. An extended discussion of methods, results, and conclusions is given in Miller (1995). Histograms for total sulfur, NNP, and paste pH determinations are provided in Figures 1b, 1c, and 1d.

For the igneous waste rock at both mines, there are two direct correlations. One between percent total sulfur and pyritic or nitric soluble sulfur (Figure 1) and another between percent total sulfur and NNP (Figure 2). These correlations mean that almost all sulfur is reactive and, excluding the paleosedimentary units, the igneous waste has very little neutralizing potential (Miller, 1995). Using the single criterion of <0.20% total sulfur is clearly not acceptable. Some very low sulfur igneous samples, between 0.25 and 0.39%, when subjected to humidity cell testing, either produced highly acidic leachate initially or at some time during the leaching procedure (Figure 3). Therefore, simply using the one criterion proposed by ZMI alone does not appear to adequately differentiate reactivity associated with various waste rock types.

Paste pH results indicated that this additional criterion was useful in identifying material which was already acidified even though a number of these samples contained very little sulfur (Figure 4). Where the paste pH was 6.0 or above, acidic pHs in humidity cell leachates were not produced. A paste pH < 6.0 identified rock types which had already reacted and contained stored oxidation products even though they contained very little sulfur.

Kinetic results clearly showed that when the sample had no NP the humidity cell invariably produced acidic leachate (Figure 5). Igneous waste rock, even at very low sulfur concentrations, having no NP or negative NNPs should be considered as potentially acid generating. In summary, no cell which met these criteria: total sulfur $\leq$ 0.20%, paste pH $\geq$ 6, and NNP $\geq$ 0 developed acidic leachate below pH 6, produced substantial sulfate, or released elevated levels of metals in leachates (Figure 4). These findings agree with statements made in the literature that no documentation has been made that can confirm that an NNP > +20 is necessarily valid when predictions are made (Ferguson and Robertson, 1994).

Figures 3 through 6 provide both the short- and long-term individual test results for comparison with static data. The most important aspect to note when viewing these figures is the very good separation of data points for the final kinetic pH. Either the cell leachate pH was maintained above 6.0 or the leachate pH fell to below 4.0 illustrating a clear separation for final pH results and possibly indicating that the reactions had gone to completion.

Although not shown in any figure, results conducted to evaluate reclamation capping and layering indicated that the use of neutral waste rock which met the previously mentioned criteria would be preferable over the use of limestone cover. Leachate results also indicated that the use of unmineralized limestone as an underdrain was preferable to the use of waste rock.

Three geochemical groups exist based on total sulfur content, NNP, paste pH, and humidity cell response: 1) Archean amphibolite gneiss and Paleozoic sedimentary shale, limestone, and dolomite; 2) Tertiary igneous syenite porphyry; and 3) Tertiary breccia, quartz monzonite and trachyte porphyry and Archean quartzite and felsic gneiss. Static data for these three rock groups were tabulated in Table 3 and sorted using the various segregation criteria (Figures 1b, 1c, and 1d) supported by the kinetic data.

Archean Amphibolite Gneiss and Paleozoic Sedimentary Rock Units - Group 1

The majority of these rock types would be suitable as reclamation material or fill. These rocks are easily recognized in hand specimen adding to the certainty that they will be segregated and stockpiled properly. This rock group had substantially lower average total sulfur values (averaging 0.35%) and a significantly higher average NNP (approximately 95 t/Kt) than the other rock groups. This group as a whole did not generate substantial sulfate, elevated metals, or humidity cell leachate below a pH of 6. Therefore, amphibolite gneiss and shale with a total sulfur content equal to or less than 0.80%, NNP $\geq$ 0, **and** a paste pH of 6.0 or greater should be stockpiled for construction, fill, and reclamation purposes. The unaltered carbonate rock units are suitable for any purpose and do not have to meet the total sulfur criteria due to possible interferences from gypsum.

Results, although not conclusive, did indicate that if a considerable amount of amphibolite could be blended with the more reactive rock, some buffering would occur. This mitigation may be realistic to implement depending on the amount of amphibolite which may be made available as a result of mining (Table 1 and Attachment A).

Tertiary Syenite Porphyry - Group 2

A discrete portion of this igneous rock type was determined to be suitable for use as reclamation material. At low sulfur levels the syenite was not considered capable of generating acid in sufficient quantities to affect revegetation (Plantenberg, 1995). This rock type was not considered suitable for use where there was a high probability that it would come in contact with surface water. Therefore, syenite porphyry waste would not be considered suitable if used as underdrain material or as fill in a defined drainage.

Tertiary syenite porphyry had a higher average total sulfur content (0.70%) and a much lower average NNP of -16 t/Kt than Group 1. This reflects a moderate acid producing potential and a lack of neutralizing potential. Higher than average sulfur samples, > 1.00%, produced sulfate and acidic leachates, especially if the sample lacked neutralizing potential. Samples with NNP > 0 t/Kt, a lower sulfur content of < 1.00%, and a paste pH of > 6.5 did not produce substantial sulfate, elevated metals, or acidic leachate below pH 6.0. However, due to its inherent low NP, a lower sulfur cutoff of 0.2% was determined to be more prudent. Syenite waste rock used as reclamation cover material would meet these criteria: $\leq$ 0.2% total sulfur, a paste pH $\geq$ 6.5, **and** an NNP $\geq$ 0 t/Kt. This requires an NP:AP ratio of 1 or greater.

Other Tertiary Igneous and Archean Metamorphic Rock Units - Group 3

The remaining rock types: breccia, quartz monzonite, quartzite, trachyte porphyry, and felsic gneiss would be produced in smaller volumes as a result of further mining. These rock types produced unfavorable or inconclusive static and kinetic results. Very limited static testing was conducted for the trachyte and breccia (Table 3). This group had the highest average total sulfur content (0.98%) and greater variability with concentrations ranging from 0 to 15.30%. NNPs were most variable for this category ranging from -478 to +89 t/Kt. This group had the lowest average paste pH, 7.2. Low sulfur samples of $\leq$ 0.80% were nonreactive unless they contained very little or no NP. The trachyte and felsic gneiss generated higher paste pHs than did the breccia and monzonite. Static data indicated that the trachyte and felsic gneiss rock types did have the potential to generate net acidity, however kinetic data were unfavorable or inconclusive. Breccia and quartz monzonite rock types with very low sulfur content and low or no NP produced initially low pH leachates at the onset of leaching or developed acidic conditions at some time during the test. These rock types may generate acid or contain oxidation products sufficient to produce low pH conditions. Therefore, this group of rock types was excluded from use as construction, reclamation, fill, or underdrain material.

RECOMMENDATIONS and ASSOCIATED RISK

Underdrains, unlined pond systems, or fill within a defined drainage should be built with unmineralized, coarse, and durable limestone or dolomite to decrease the risk involved with placing potentially acid producing rock in a drainage.

Qualitatively, the risk that material segregated using the criteria identified in this study will produce significant acid is low. Identification of waste rock using the newly defined criteria will allow effective segregation and stockpiling of suitable reclamation materials.

Capping of reactive waste rock lowers the risk that coversoil material will become acidified and negatively affect vegetation. The use of neutral waste rock as a cap will provide a neutral to slightly acidic rooting environment which is favored by evergreens and plants in general. Generally, the higher pH limestones, if used as the waste rock cap, might limit nutrient availability to vegetation if pHs are above 8. Also there is sufficient evidence that indicates that the use of limestone material as a cap may in fact exacerbate acid production.

There is no risk involved in acquiring sufficient neutral material for use as reclamation or underdrain material. Should an insufficient quantity of suitable waste rock exist, paleosedimentary rock is available from unmineralized areas nearby in sufficient quantities for successful completion of construction, reclamation, and/or remediation activities under any alternative (Attachment A).

In the past, feasibility studies have focused mainly on the economics of the ore body without identifying realistic costs for reclaiming and remediating reactive waste in an environmentally safe manner. In the future, these techniques could be used during advanced exploration or early developmental stages of a project. Production, collection, and interpretation of these types of data early on, with documentation of the existing water quality in a particular target area, will help protect the environment from contamination and the operator from the liability incurred later when mining a reactive ore deposit.

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The authors wish to recognize Zortman Mining Inc. for its cooperation and expenditures in the effort to advance this remediation study and the mines' expansions. In particular, thanks are extended to Marianne Caballero and Tom Byrne, metallurgical technicians with ZMI, who conducted the majority of the paste pH and static testing. Dr. Charles W. Russell contributed to this study with his interpretation of the genesis and alteration of the deposit with respect to sulfide occurrences. The Zortman research group including Terry Hertel, and Schafer and Associates, Bozeman, Montana succeeded in narrowing the total sulfur brackets for waste and providing much information regarding the reactivity of ore and lime/limestone amendments. The authors wish to express gratitude to the agencies for their cooperation and Fran O'Hara for her assistance in preparing this document.

Table 3. Zortman Waste Rock Summary of Static Data by Lithology and by Various Sets of Criteria

		Total Sulfur (wt.%)			Paste pH (s.u.)			NNP (t $CaCO_3$ eq./Kt)		
Lithology	n	Min	Max	Average	Min	Max	Average	Min	Max	Average
Syenite	343	0.01	9.66	0.86	3.8	10.0	7.7	-301	20	-23
Monzonite	105	0.00	3.29	0.54	4.1	9.4	7.6	-102	5	-14
Trachyte	2	0.57	1.67	1.12	5.3	7.6	6.5	-52	-13	-33
Felsic gneiss	73	0.01	6.53	1.10	3.3	9.4	7.0	-207	40	-30
Amphibolite	28	0.01	4.09	0.59	6.5	9.0	8.1	-124	94	6
Quartzite	15	0.01	4.70	0.98	---	---	---	-130	13	-23
Breccia	2	0.39	1.63	1.01	3.5	4.7	4.1	-51	-12	-31
ALL SAMPLES	568	0.00	9.66	0.82	3.3	10.0	7.6	-301	94	-21
All samples with ZMI proposed criteria of < 0.2% sulfur	147	0.00	0.19	0.08	5.3	10.0	8.4	-7	81	3
All syenite samples with criteria[1]	44	0.01	0.17	0.07	7.1	10.0	8.6	0	15	3
All amphibolite and sedimentary samples with criteria[2]	18	0.01	0.75	0.16	8.1	8.6	8.3	1	81	22

Source: ZMI data, 1993 developmental drilling

[1]Syenite criteria are $\leq$ 0.2% S_{TOT}, $\geq$ 0 NNP, and $\geq$ 6.5 paste pH

[2]Amphibolite gneiss and paleosedimentary units criteria are $\leq$ 0.8% S_{TOT} and $\geq$ 6.0 paste pH

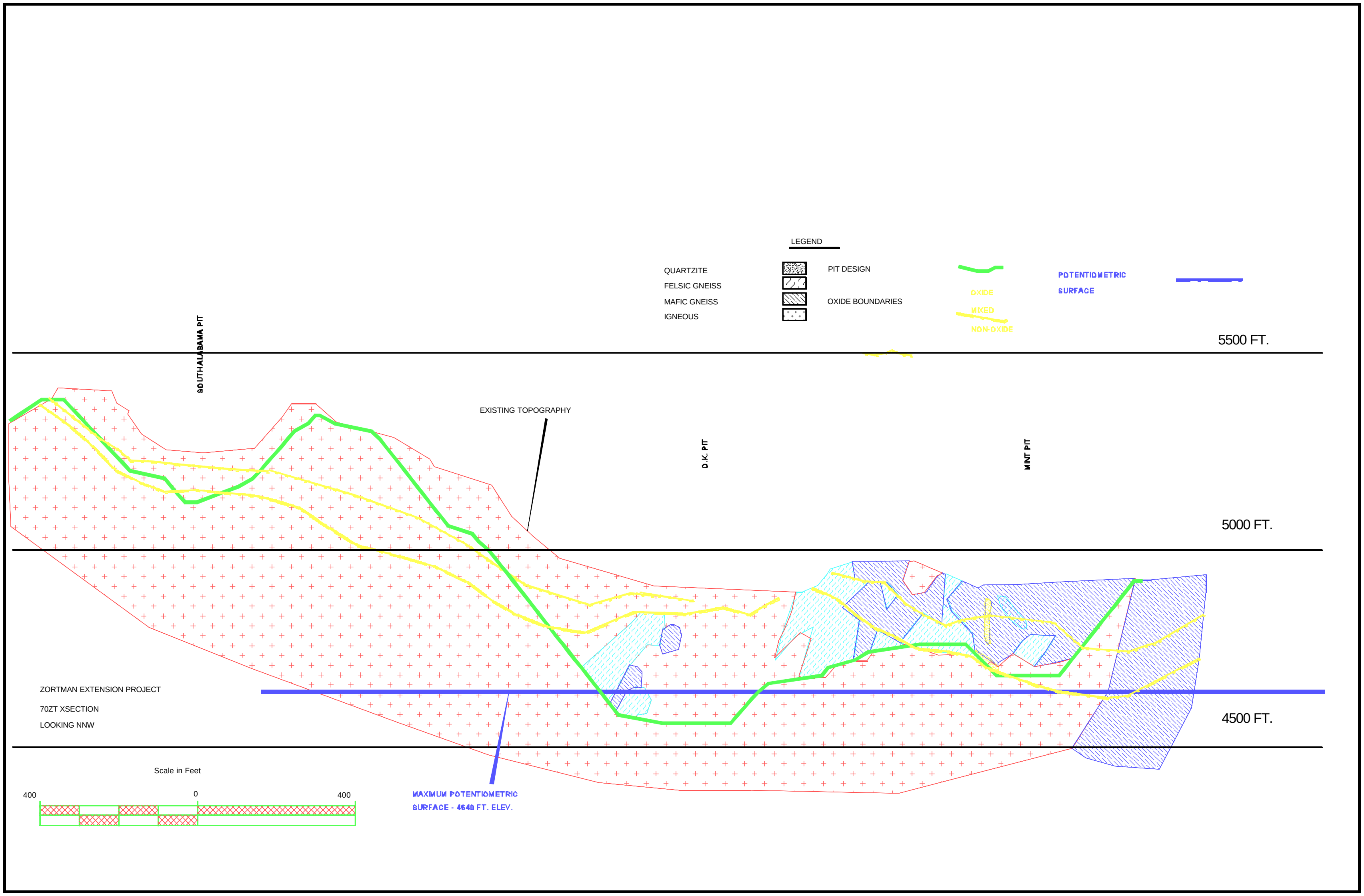


Figure 1a. Geologic cross-section looking NNW. Existing and proposed South Alabama, OK, and Mint pits for the Zortman Extension Project.

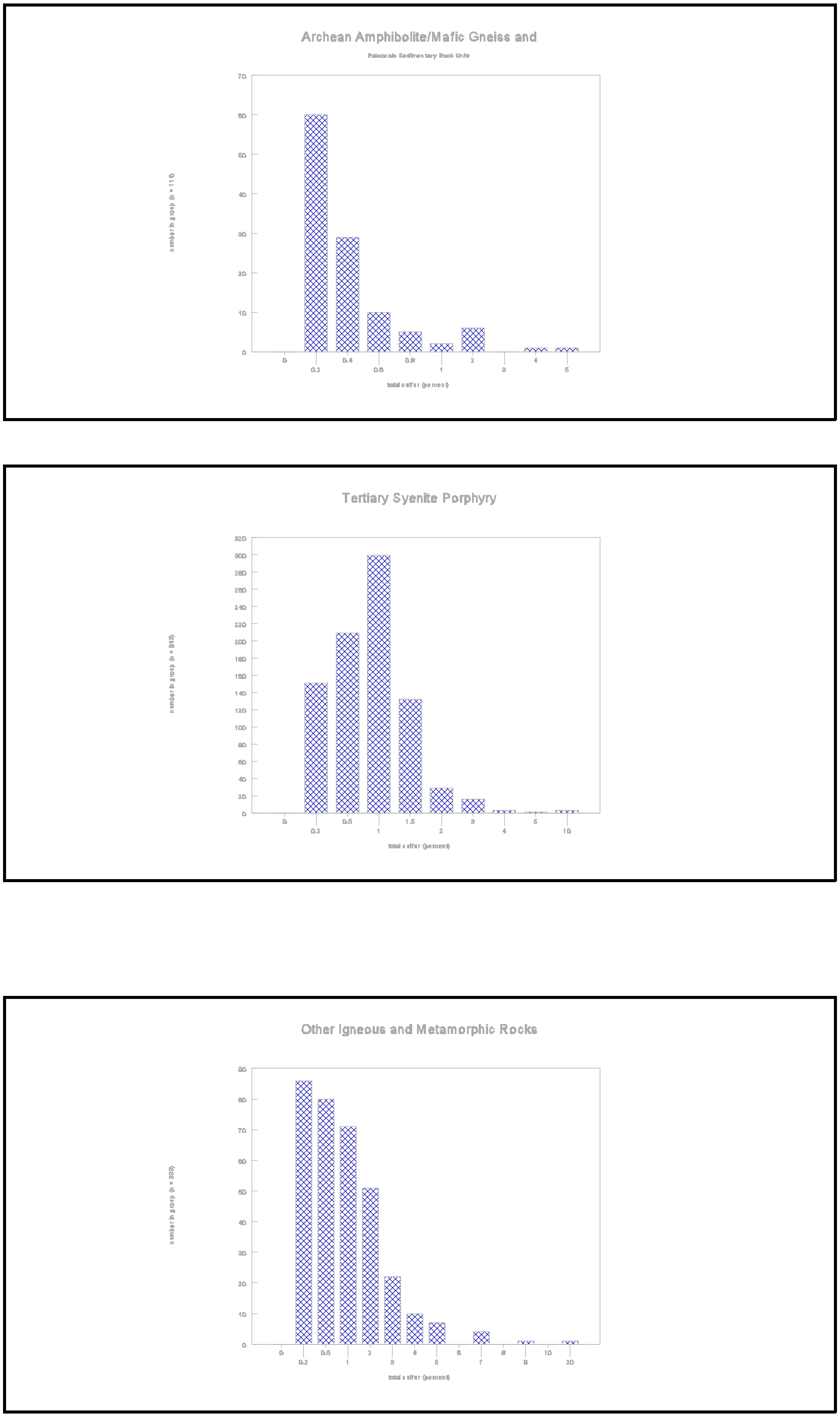


Figure 1b. Total sulfur frequency distribution for all samples.

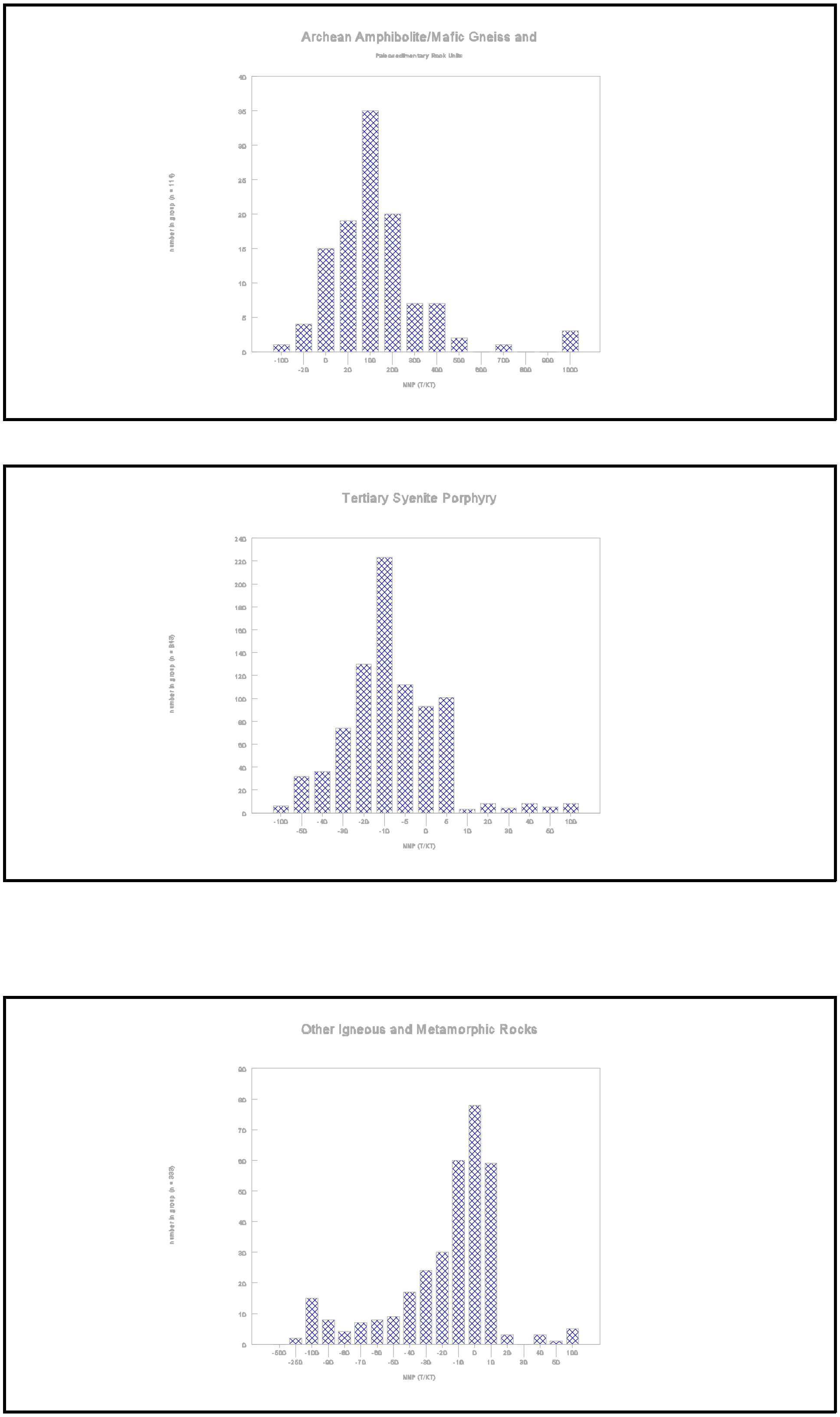
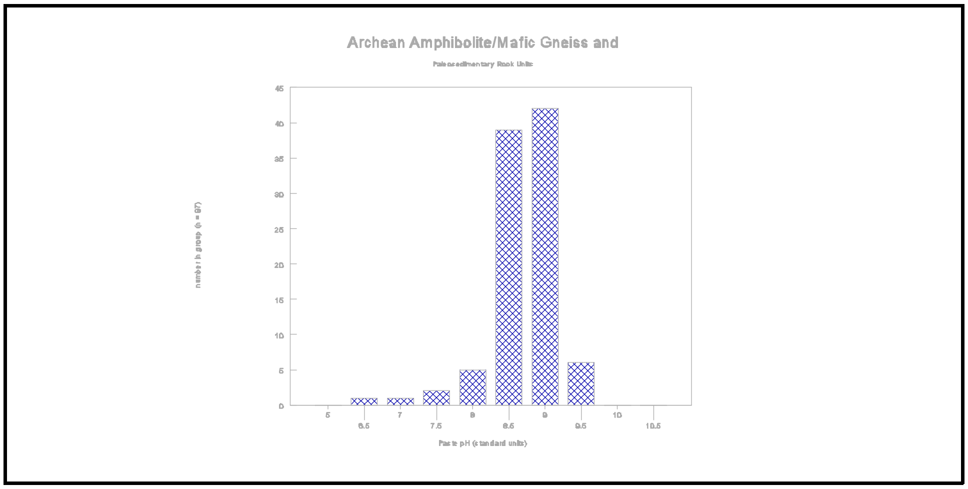
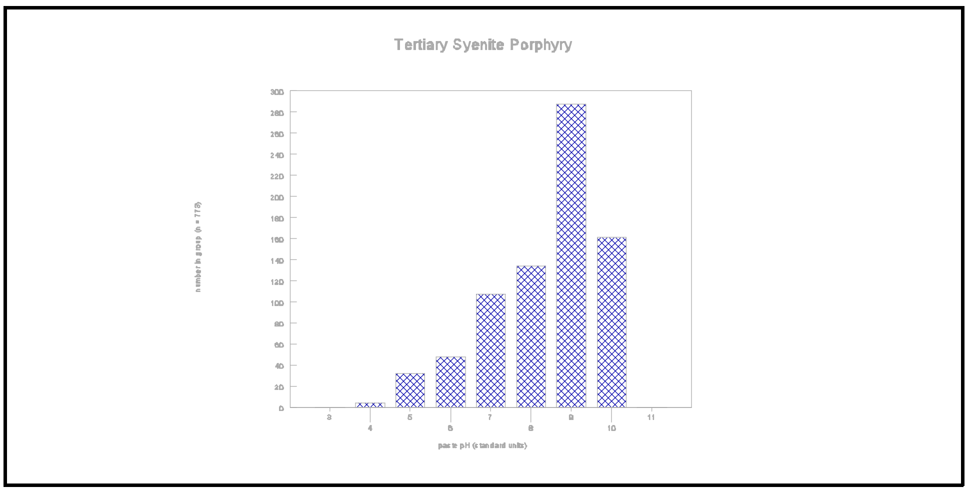


Figure 1c. NNP frequency distribution for all samples.





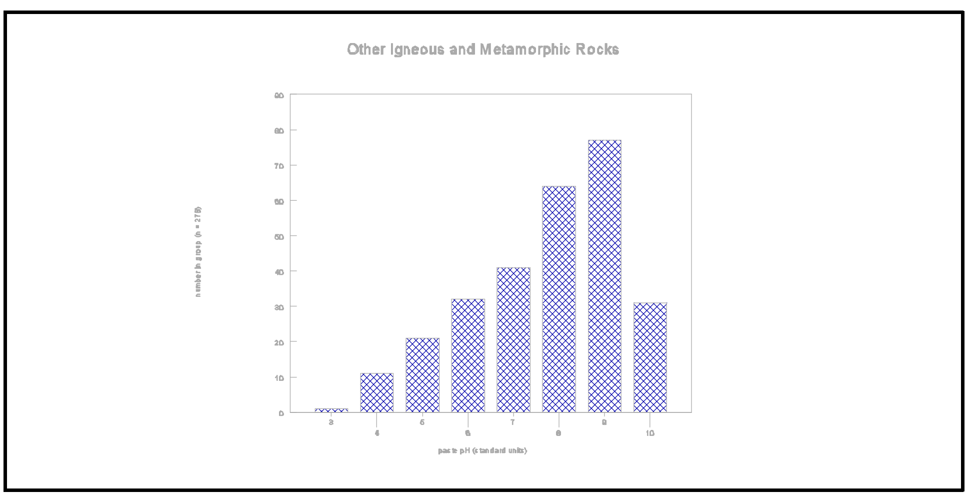
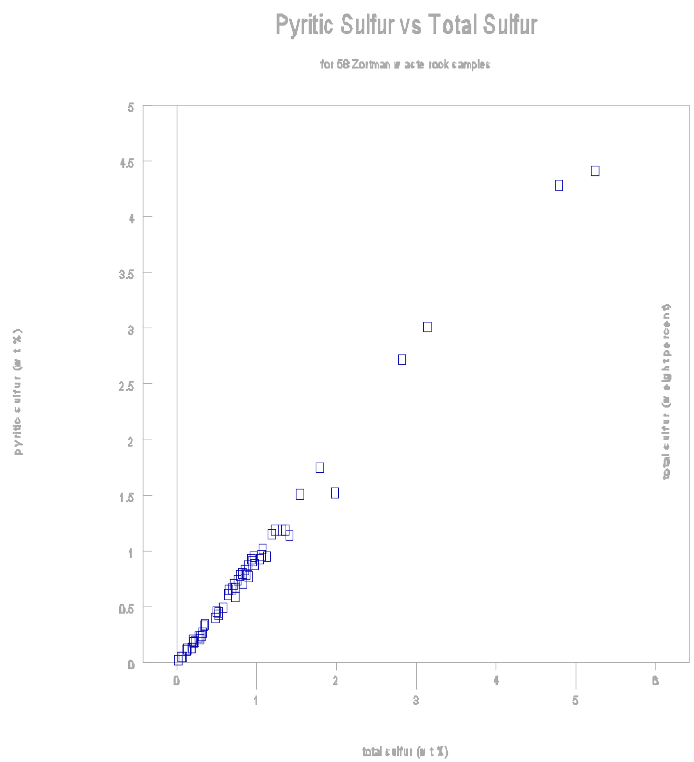


Figure 1d. Paste pH frequency distribution for all samples. pHs were not conducted for all samples.



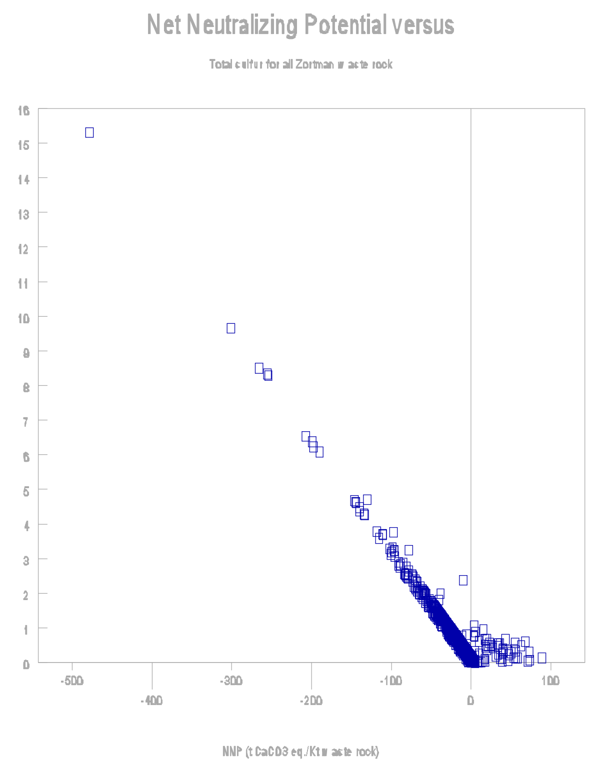
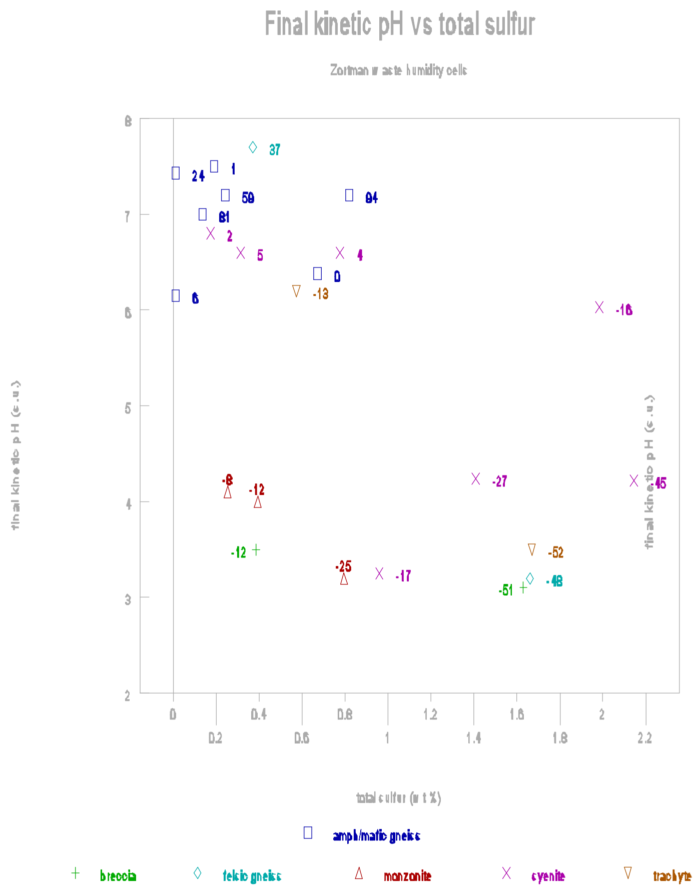


Figure 1. Pyritic (nitric soluble) sulfur vs total sulfur for 57 Zortman waste rock samples.

Figure 2. Total sulfur vs NNP for all Zortman waste rock samples.



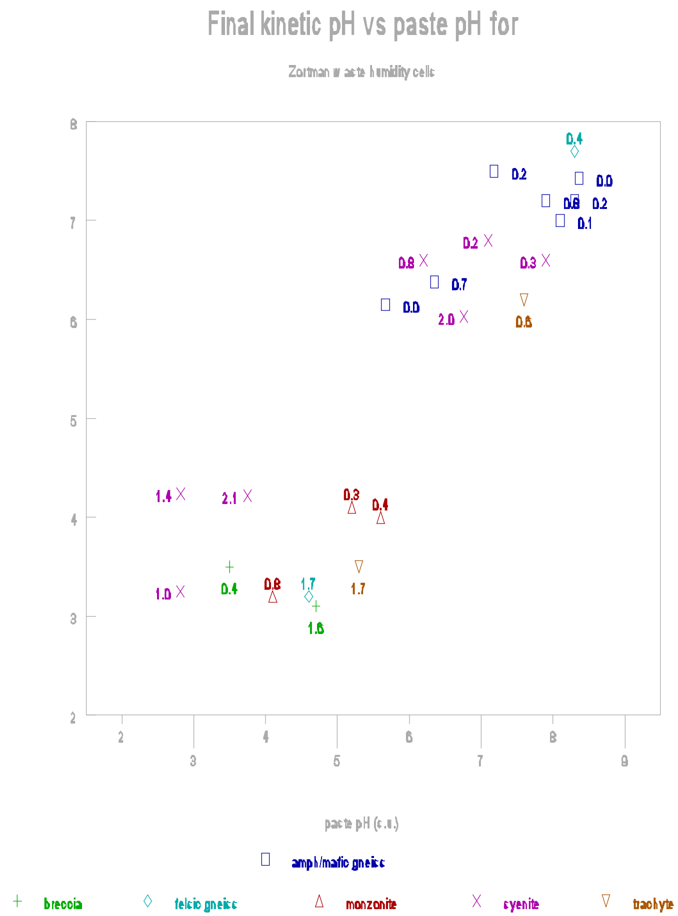
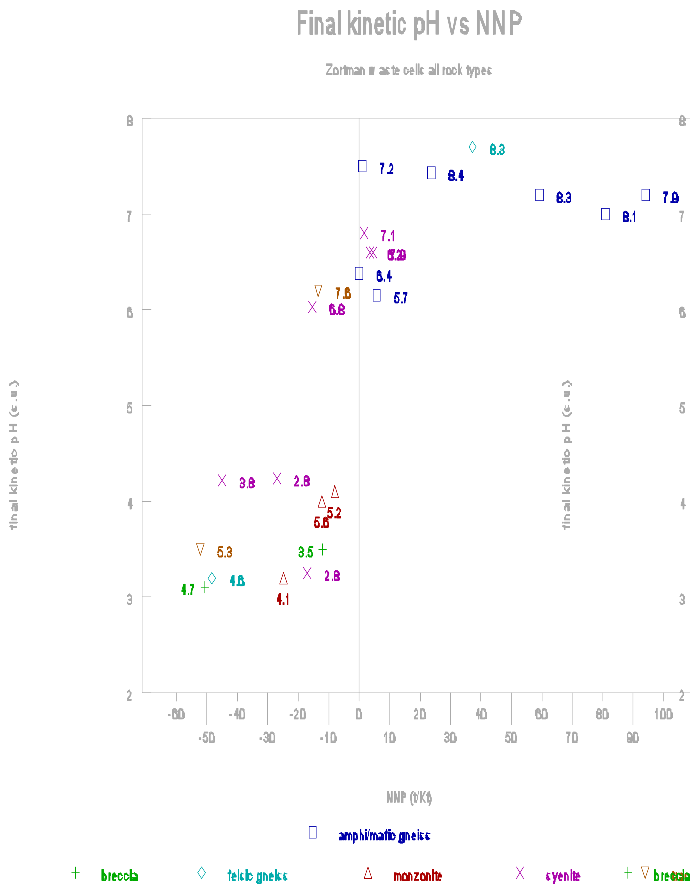


Figure 3. Final kinetic pH vs total sulfur for all rock types. NNP label (t $CaCO_3$ eq./Kt waste rock). Some low sulfur cells with negative NNPs produced acidic leachate.

Figure 4. Final kinetic pH vs paste pH for all rock types. Total sulfur label (wt %). Cells with paste pHs $\geq$ 6 produced leachates with pHs $\geq$ 6 after 45 weeks.



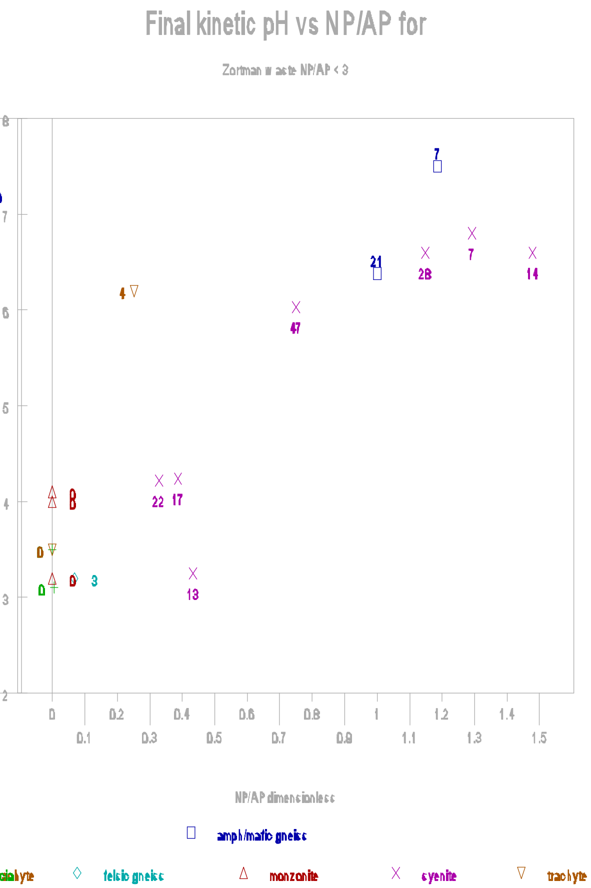


Figure 5. Final kinetic pH vs NNP for all rock types. Paste pH label (s.u.). No cells with an NNP greater than 0 produced acidic leachate below pH 6.

Figure 6. Final kinetic pH vs NP/AP for all rock types. NP label (t $CaCO_3$ eq./Kt). Rock types with NP = 0 all produced acidic conditions.

ATTACHMENT A - Materials Requirements and Sources - Zortman Alternative 7

RECLAMATION MATERIALS	SOURCE (Location/Acres)	VOLUME AVAILABLE (million cubic yards)	RECLAMATION VOLUMES NEEDED - MILLION CUBIC YARDS (Acres covered by rec cover material thickness)				TOTAL MATERIAL NEEDED (myd³)
			Water Balance (12" TS, 24" SS, 12" Neutral Waste)	Water Barrier (12" TS, 36" Neutral Waste)	Pit Benches (12" TS, 12" Neutral Waste)	Non-Acid Areas (12" TS)	
TOPSOIL (TS)	Existing Stockpiles/Reclamation	0.183/0.08	0.646	0.424	0.081	0.219	1.370
	Goslin Flat*	0.567					
Total Topsoil Available		0.830	Topsoil Surplus or Deficiency				-0.540+
SUBSOIL (SS)	Existing Stockpiles	0	1.291	0	0	0	1.291
	Goslin Flat*	2.215					
Total Subsoil Available			Subsoil Surplus or Deficiency				0.924++
Suitable Reclamation Materials	Existing Stockpiles	0.0	0.65 million	1.32 million	0.08 million	n/a	2.03 million
	Ruby Gulch Tailing	0.4					0.0
	Goslin Flat* (subsurface gravels)	1.0+					0.4
							1.0
	Neutral Waste Rock Produced during Mining (est.)**	2.5					0.63
Total Suitable Material Available		3.9	Neutral Waste/Material Surplus (if leach pad is in Goslin Flat)				+0.65

*Goslin Flat presently undisturbed. Would be mined during development of leach pad.
**Based on ZMI's 0.2% total sulfur criterion an estimated 5.5 million yd³ of neutral waste rock would be produced during expansion mining. For this analysis, the author's analysis has assumed that 1/2 of that material would be suitable for use in reclamation covers
+Deficiency may be made up using surplus from Landusky mine.
++Surplus may be used to make up deficiencies at Landusky mine.

REFERENCES

Bailey, R.L. 1974. Geology and ore deposits of the Alder Gulch area, Little Rocky Mountains, Montana. M.S. thesis unpublished. Montana State University, Bozeman. 81 pp.

Brockunier, S.R. 1936. Geology of the Little Rocky Mountains, Montana. Ph.D. dissertation unpublished. Yale University, Connecticut. 130 pp.

Ferguson, K.D. and Robertson, J.D. 1994. Assessing the risk of ARD. Proc. of the Pittsburgh conference on International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage. 1:2-11.

Giles, D.L. 1983. Gold deposits of the Little Rocky Mountains, Montana, pp. 157-162 In: The Genesis of Rocky Mountain Ore Deposits - Changes with Time and Tectonics. Denver Region Exploration Geologists Society.

Honea, R.M. 1992. Landusky polished section descriptions and Zortman-Landusky comparison; and other unpublished technical reports dated March 30, May 31, July 2, July 14, and August 3. Confidential, available at ZMI headquarters, Zortman, MT.

Miller, R.A. 1995. Identification of neutral waste rock at the Zortman and Landusky mines, Little Rocky Mountains, Phillips County, North Central Montana. Unpublished technical report supporting the 1995 Draft EIS for the Zortman/Landusky mine extensions. Available DEQ Helena, MT.

Plantenberg, P. 1995. Montana DEQ. Personal communication regarding plant growth.

Richardson, G.L. 1973. Geology and ore deposits of the Landusky Mining District, Phillips County, Montana. M.S. Geology. Univ of Arizona, Tucson. 64 pp.

Russell, C.W. 1991. Gold mineralization in the Little Rocky Mountains, Phillips County, Montana. Montana Bureau of Mines and Geology, Special Publication 100. 38 pp.

Saskatchewan Environment and Public Safety. 1992. Mine Rock Guidelines: Design and Control of Drainage Water Quality. Report No. 93301, prepared by Steffen Robertson and Kirsten (B.C.) Inc.

US Department of the Interior, Bureau of Land Management and Montana Department of State Lands (USDI and DSL). 1993. Supplemental Environmental Assessment for Landusky Mine Operating and Reclamation Plan Modifications: Acid Rock Drainage Control and Remediation. 91 pp.

White, P.J., and Lawless, J.V. 1989. Geochemistry of porphyry-hosted Au-Ag deposits in the Little Rocky Mountains, Montana. Econ Geol. 84:970-971.

Zortman Mining Inc. (ZMI). 1992. Application for amendment to Operating Permit No. 00096; Vols. 1-7 and subsequent revisions.